GRAIN-SIZE ANALYSIS OF SURFACE MATERIAL UNDER WIND EROSION USING THE EFFECTIVE SURFACE CONCEPT

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ABSTRACT

The grain mobility and roughness of a surface exposed to wind are dependent on the grain size of the surface particles. This paper deals with the temporal variation in the grain size of surface material using an analytical method based on the effective surface concept. The analysis of grain size data obtained from a wind tunnel experiment indicated that, above the threshold wind friction velocity for all surface particles, the grain-size distribution of surface particles was very similar to that of the parent material over a time period of 10 to 15 minutes. However, the mean grain size of surface particles apparently decreased over the initial time period of 2 to 3 minutes. We therefore confirm earlier studies that on a non-uniform grain bed a larger particle could be more mobile than a smaller particle if the wind friction velocity was higher than the threshold for the larger particle. However, this does not imply that the largest particle is most mobile due to the non-linear dynamics of aeolian sediment transport processes. © 1997 by John Wiley & Sons, Ltd.

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INTRODUCTION

The surface material is the major input to the aeolian transport process. There is a general consensus about the importance of the grain-size characteristics of surface material on sediment transport by wind. This has developed from wind tunnel experiments on selected size-distribution parent material (e.g. Butterfield, 1991; Gillette and Stockton, 1989; McKenna-Neuman and Nickling 1989; Nickling, 1988; Rasmussen and Mikkelsen, 1991; Williams *et al*., 1990; Willetts, 1983; Willetts and Rice, 1988) and theoretical modelling of grain-particle saltation (e.g. Owen, 1964). However, these earlier studies focus on the overall transport rate of all size classes and do not consider the transport rate of individual size classes. As a result, little is known about the important role of the grain-size characteristics of surface material on the aeolian sediment transport of individual size classes. Anderson *et al*. (1991) observe that experimental and theoretical research to date has focused on the single grain-size bed, and McEwan and Willetts (1993) conclude that our understanding of the grain-size characteristics of the surface materials is still inadequate.

Gillette and Stockton (1989) investigated the effect of non-erodible (relatively coarse) particles on the wind erosion of erodible (relatively fine) particles. They found that non-erodible particles increase the threshold friction velocity for entrainment of erodible surface particles. Nickling (1988), in a study of particle movement initiation by wind, suggests that the fluid threshold velocity for any sediment should be a threshold range which is associated with parent material grain size and grain-size distribution.

The studies of Gillette and Stockton (1989) and Nickling (1988) were undertaken in a wind tunnel. The grain-size characteristics of the parent material surface were known at the beginning, but not for the rest of the experiment. Other studies conducted in the field have investigated the grain-size characteristics of transported sediment, but did not explore the temporal change in the grain-size characteristics of the surface particles.

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Gillette and Walker (1977) collected the sediment transported by wind over two differently textured soils (fine sand and loamy fine sand). They found that most of the horizontal flux of particles takes place in the height interval of 0–1·3 cm, and that the grain-size distribution of particles transported in that height interval resembles the grain-size distribution of the parent soil. Nickling (1983) collected transported sediment for an area of proglacial fluvial deposits during dust storms. He found that the sediment transported in surface creep is significantly coarser than that transported in saltation. His analysis shows that the grain-size distribution of creep particles is positively skewed, and the grain-size distribution of saltation particles is negatively skewed.

It is appropriate to separate the surface material from the parent material in sediment transport studies, because the surface material rather than the parent material is exposed to the fluid and directly influences fluid dynamics and sediment transport. If sediment deposition takes place over a surface, the grain-size distribution of the surface will be the same as that of the deposited particles. However, if sediment erosion takes place over a surface, the grain-size distribution of the surface will be a function of the grain-size distributions of both the parent material and the eroded material, and will also be dependent on the thickness of the eroded layer. Because sediment erosion by water or wind is a selective process, the grain-size distribution of the surface under erosion can vary considerably over time, particularly over the long term. Lyles and Tatarko (1986) indicate the influence of wind erosion on soil surface texture by comparing the grain-size distribution of soil particles sampled in the same sites in 1948 and 1984. They found increases in the sand fraction ranging from 0·9 to 23·3 per cent. The average changes in grain-size distribution at all sites were +6·5,–7·2 and +0·7 per cent for sand, silt and clay, respectively. Understanding the nature and cause of these changes requires a time series analysis of the aeolian sediment entrainment and transport processes.

This study investigates temporal change in the grain-size characteristics of surface particles under aerodynamic erosion conditions. We first introduce the effective surface concept. Then, we derive a method, based on this concept, to calculate the grain-size distribution and the mean grain size of surface particles over time from the observed sediment flux over time. This method is applied to data collected in two series of wind tunnel experiments. The results are compared with findings of other studies on aeolian sediment transport rate for individual grain size classes over time.

THE EFFECTIVE SURFACE CONCEPT

The grain-size distribution of a particle surface over time can be determined using high-speed camera photography and image analysis techniques (e.g. Willetts and Rice, 1988; Williams *et al*., 1990; Willetts *et al*., 1991). This empirical method is costly, sophisticated, and instrument-dependent. Barndorff-Nielsen and Sørensen (1991) propose a theoretical method for the prediction of the temporal and spatial variation of the size distribution of particles on a surface under erosion or deposition. They assume that the size distribution of the surface particles is initially log-hyperbolic and that this type of distribution persists over time. They then define a probability density function for the hyperbolic distribution of surface particles by a set of parameters including a key parameter indicating erosion and deposition. Because there is no reliabile solution, empirical or theoretical, for the temporal and spatial variation in erosion or deposition, particularly over a long term, Barndorff-Nielsen and Sørensen (1991) state that their method could be invalid when applied over a longer time period. We believe there is another problem with this theoretical method; that is, the method does not specify the thickness of the reference surface to which the grain-size distribution applies. The thickness (elevation) of the reference surface varies over time due to erosion or deposition. Furthermore, selective erosion (sorting) could introduce a difference in the grain-size distribution of particles between the surface particles and the underlying parent material particles.

The basic concept of the effective surface introduced by Li and Martz (1994, 1995) was used for the development of a system of numeric models for sand-particle transport by wind and for the examination of sand-particle dislodgement from a multiple-grain bed by wind. The basic concept was incomplete as it considered only particle surfaces under erosion. Here, the basic concept is extended to consider particle surfaces under deposition.

The effective surface is the top, thin layer of particles on a sediment surface. This layer is exposed to the wind and is the source from which particles are dislodged, or the sink in which particles are deposited. While the

volume of the effective surface should ideally be constant, it will vary over time as a result of erosion or deposition. In our application of the concept, erosion and deposition are evaluated over discrete time periods and the condition of a constant volume is approximated by adjusting the volume of the effective surface at the end of each discrete time period as outlined in the following section.

At the end of each time period in which erosion is taking place, the volume of the effective surface is reduced by the volume of the particles eroded during that time period. Particles must be added to the effective surface from the parent material to re-establish the initial volume. The volume of particles eroded determines the volume of particles added. However, the grain-size distribution of the added particles is that of the parent material, not that of the eroded particles. If the parent material particles on the bed are uniformly distributed with depth, then no difference in texture exists initially between the effective surface and the parent particles. However, a difference develops over time through selective dislodgement by wind and this distinguishes the effective surface from the parent material.

If deposition is taking place, a volume of particles equal to that of the deposited particles must be removed from the effective surface at the end of each time period. The grain-size distribution of the removed particles is that of the effective surface, not that of the deposited particles. However, if there is no temporal variation in the grain-size distribution of the deposited particles, the grain-size distributions of the effective particles and the deposited particles can be the same.

The initial thickness of the effective surface (i.e. the volume of the effective surface per unit area) must be established prior to analysis. It should be chosen as small as possible, but no smaller than the largest diameter of the parent material particles and no smaller than the equivalent thickness of particles eroded or deposited over any specific time period. If the effective surface is thinner than the diameter of the largest particle, all large particles whose diameter is larger than the thickness of the effective surface will be eliminated from consideration. If the thickness of the effective surface is smaller than the equivalent thickness of particles eroded or deposited over a specific time period, some exposed particles will be excluded from the effective surface. If the effective surface is too thick, there will be too many parent material particles included in the effective surface.

GRAIN-SIZE CHARACTERISTICS OF THE EFFECTIVE SURFACE PARTICLES

The grain-size distribution of the effective surface is determined by the grain-size distribution of the parent material particles and the particles eroded from or deposited at the surface. At the end of the time period t_j, the weight of effective surface particles in size class $\mathrm{d_i}$, $\mathrm{Wx(d_i, t_j)}$, is:

$$Wx(d_i,t_j) = Wp(d_i, t_{j-1}) + \Delta W(d_i, t_j) \tag{1}$$

where $Wp(d_i, t_{j-1})$ is the weight of effective surface particles in size class i in the previous time period t_{j-1}, and $\Delta W(d_i, t_j)$ is the change in the weight of effective surface particles in size class d_i in time period t_j due to erosion or deposition. $\Delta W(d_i, t_j)$ is negative when the surface particles are being eroded and positive when the transported particles are being deposited.

To ensure a constant thickness of the effective surface, the volume of the effective surface must be adjusted at the beginning of each time period. The adjustment weight of particles for size class d_i at the end of time period t_j for the surface under erosion, $Wa(d_i, t_j)$, is:

$$Wa\,(d_i, t_j) = \Phi_1(d_i, 0) \sum_{i=1}^{i=n} - \Delta W(d_i, t_i) \tag{2}$$

where $\Phi_1(d_i, 0)$ is the frequency by weight of parent particles of size class d_i. The adjustment weight of particles for size class d_i at the end of time period t_j for the surface under deposition, $Wa(d_i, t_j)$, is:

$$Wa\,(d_i, t_j) = \Phi_2(d_i, 0) \sum_{i=1}^{i=n} - \Delta W(d_i, t_i) \tag{3}$$

where $\Phi_2(d_i, 0)$ is the frequency by weight of the effective surface particles of size class d_i. By definition, $Wa(d_i, t_j)$ is positive under erosion conditions, and negative under deposition conditions.

The grain-size distribution of the effective surface particles at the beginning of each time period is given by:

$$\Phi(d_i, t_j) = \frac{Wx\,(d_i, t_j) + Wa\,(d_i, t_j)}{W} \tag{4}$$

where W is the constant weight of effective surface particles. Unlike Barndorff-Nielsen and Sørensen's (1991) theoretical method, this method uses the actual grain-size distribution, is free of assumptions on the initial grain-size distribution, and specifies the thickness dimension of the effective surface. It should be noted that this method is not proposed for prediction but for calculation of the grain-size distribution and the mean grain-size of the effective surface. However, this simple method can be used to predict precisely the grain-size distribution and the mean grain size of the surface over time, given an accurate input of $\Delta W(d_i, t_j)$ due to erosion or deposition.

The mean diameter of effective surface particles $D(t_j)$ is a function of the grain-size distribution $\Phi(d_i, t_j)$:

$$D(t_j) = \sum_{i=1}^{i=n} d_i \phi(d_i, t_j) = \frac{1}{W}\left[\sum_{i=1}^{i=n} d_i Wx(d_i, t_j) + \sum_{i=1}^{i=n} d_i Wa(d_i, t_j)\right] \tag{5}$$

APPLICATION OF THE EFFECTIVE SURFACE CONCEPT

The effective surface concept was established so that we can infer the grain-size characteristics of the bed through time from the grain-size distributions of the parent material and the eroded or deposited particles. It is easy to measure the grain-size distributions of the parent material and the eroded sediment, but difficult to measure that of the surface under erosion without halting the experiments and thereby disturbing the system. However, using the effective surface concept, we can calculate temporal changes in the grain-size characteristics of the surface under erosion.

A series of wind tunnel experiments was conducted to examine the temporal variation in the grain-size distribution on different parent material surfaces at different wind friction velocities. The experimental data were analysed using the method based on the effective surface concept. Below we provide a brief summary of the experiments. A detailed description of the wind tunnel experiments (i.e. instrumentation, test materials and test procedures) is available in Li and Martz (1994, 1995).

A set of ten parent material test samples of known grain-size distribution were prepared from clean, dry sand such that each contained a range of particle sizes mixed in different proportions (see Figures 1 and 2 for the grain-size characteristics of the samples). Test sands were placed on a 10 cm (streamwise) x 16 cm (spanwise) bed at wind friction velocities of 0·29 m s^{-1} and 0·34 m s^{-1} (as determined from hot-wire anemometer velocity profiles), respectively, for two series of experiments. The saltation action was thought to be negligible as the bed was only 10 cm wide streamwise and the eroded particles were not recirculated through the wind tunnel. The fluid over the bed was therefore thought aerodynamically dominant.

The material eroded during each experiment was collected in a high-efficiency trap. The trap was designed so that the material eroded during each of five successive time intervals (2 minutes for the higher wind friction velocity and 3 minutes for the lower) was collected separately over the duration of each experiment. The grain-size distribution of the material eroded during each time interval was subsequently determined.

Grain-size distribution of eroded particles

The collected particles did not include all the eroded particles, since not all the eroded particles settled out in the trap. The weight of collected particles for each experiment was corrected for the trap efficiency (the ratio by weight of collected particles to the total eroded particles) for each class of particles. The total weight of eroded particles was measured by the difference in the weights of the parent sample at the beginning and at the end of each experiment. The trap efficiency varied with particle classes for individual experiments. The lowest trap

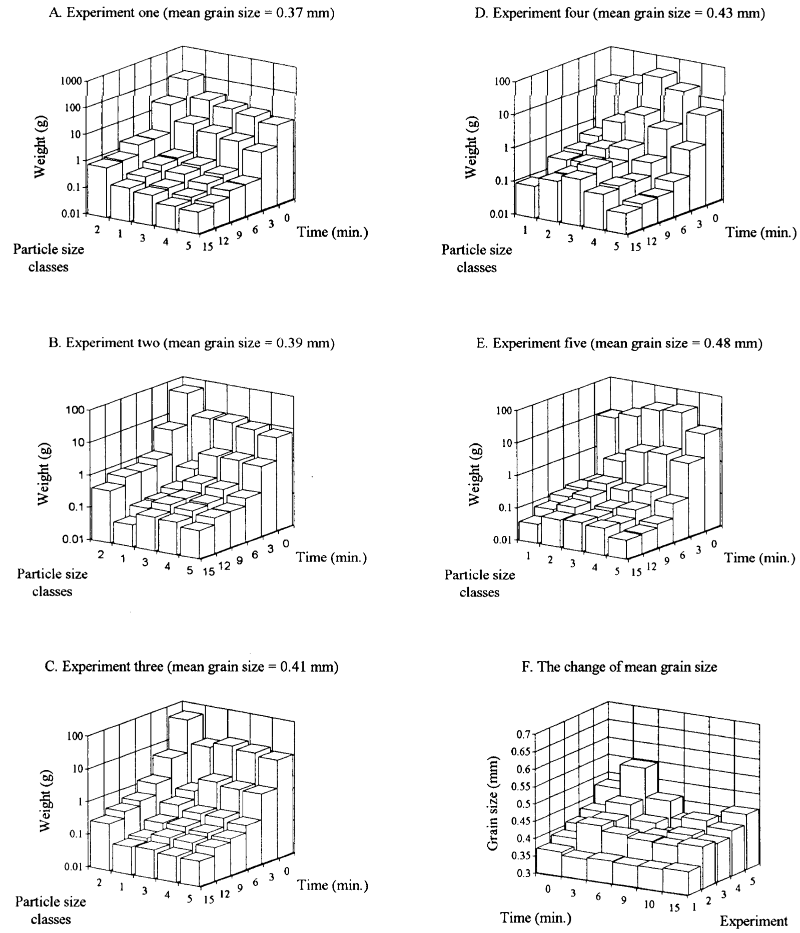

Figure 1. The grain-size characteristics of sediment eroded from different parent materials. The friction velocity $u* = 0{\cdot}29\,m\,s^{-1}$. (A–E) The distribution over time (grain-size classes: 1, 0·15–0·25 mm; 2, 0·25–0·42 mm; 3, 0·42–0·50 mm; 4, 0·50–0·59 mm; 5, 0·59–1·00 mm in diameter. (F) The change of mean grain size over time. The change of grain-size distribution and the mean grain size at time 0 are for parent material, and at other times are for eroded sediment

efficiency was 84 per cent. On average, the trap efficiency was about 90 per cent. The weight of eroded particles in different size clases was found by dividing the weight of the collected particles by the corresponding trap efficiency.

In order to make a realistic comparison, the collected particles for each time interval of each experiment were screened and grouped into five size classes identical to those used to prepare the parent material test samples (0·15–0·25 mm, 0·25–0·42 mm, 0·42–0·50 mm, 0·50–0·59 mm and 0·59–1·00 mm in diameter). There were 25 eroded material samples for each experiment, each representing the volume of sediment eroded over a specific time period for a specific grain-size class. The observed change in the grain-size distribution of the eroded material over the duration of the experiments (15 minutes at the wind friction velocity of $0{\cdot}29\,m\,s^{-1}$ and 10 minutes at the wind friction velocity of $0{\cdot}34\,m\,s^{-1}$ is illustrated in Figures 1A–E and 2A–E. Note the log-weight scale. Figures 1A–E and 2A–E show both the change in grain-size distribution and the decline in sediment transport over time.

Figures 1A–E and 2A–E show that the eroded sediment from relatively fine parent materials was very similar in grain-size distribution to the parent material. This was the case for experiments 1, 2, 3, 6 and 7, each of which had a parent material dominated by particle size class two (0·25–0·42 mm in diameter) or particle size class three (0·42–0·50 mm in diameter). In each experiment, the modal size class of the eroded sediment was the same as that of the parent material. Gillette and Walker (1977) report that the grain-size distribution of particles transported at heights of 0–1·3 cm above two different textured soils (fine sand and loamy fine sand) closely resembled the relative size

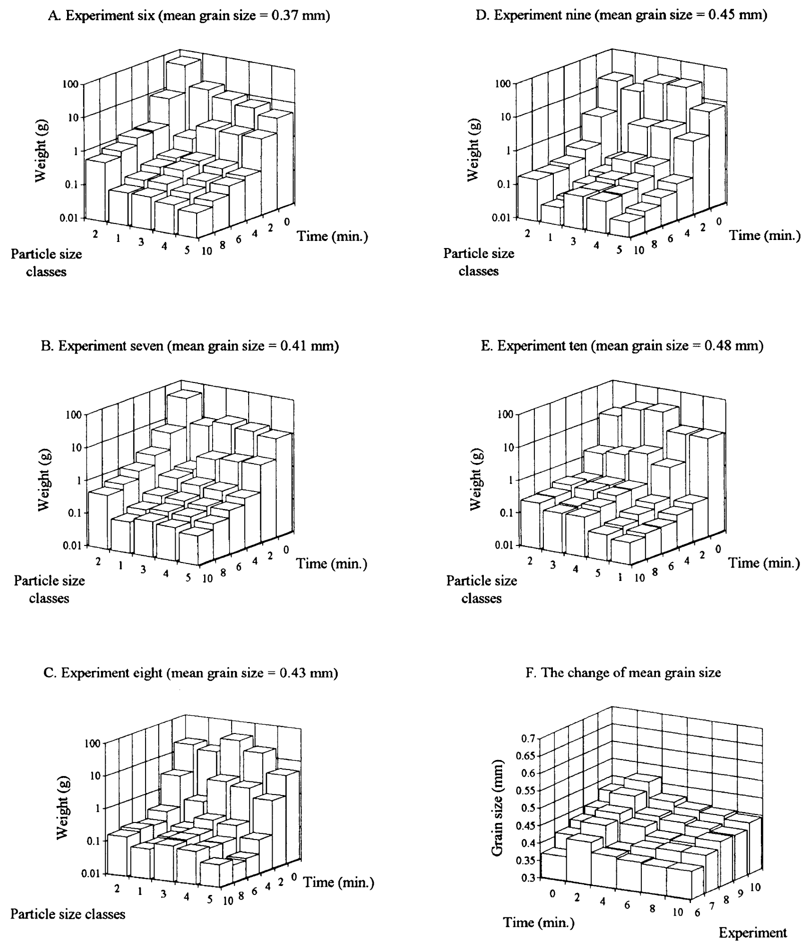

Figure 2. The grain-size characteristics of sediment eroded from different parent materials. The friction velocity $u^* = 0{\cdot}34\,\mathrm{m\,s^{-1}}$. (A–E) The change of grain-size distribution over time (grain-size classes: 1, 0·15–0·25 mm; 2, 0·25–0·42 mm; 3, 0·42–0·50 mm; 4, 0·50–0·59 mm; 5, 0·59–1·00 mm in diameter. (F) The change of mean grain size over time. The change of grain-size distribution and the mean grain size at time 0 are for parent material, and at other times are for eroded sediment

distribution of the parent soils. Our observations are in accord with their findings. Gillette and Walker (1977) suggest that this resemblance simply reflects the availability of particles from the parent material.

Figures 1A–E and 2A–E also show that, for the relatively coarse parent material, the eroded sediment differed in grain-size distribution from the parent material. The modal particle size class of the eroded sediment was smaller than that of the parent materials. This was the case for experiments 5, 9 and 10, each of which had a parent material dominated by size classes three and four (0·42–0·59 mm in diameter). This indicates that the most mobile particles were neither the finest nor the coarsest, but of intermediate size class. This demonstrates that wind erodibility played a more important role than the availability of particle supply from the parent material in this case. The availability of coarse particles was high for experiments 5, 9 and 10. However, the coarse particles required a higher threshold wind velocity for entrainment and were, therefore, more stable. The low wind erodibility of the coarse particles resulted in the discrepancy in the modal particle size class between the parent and eroded particles.

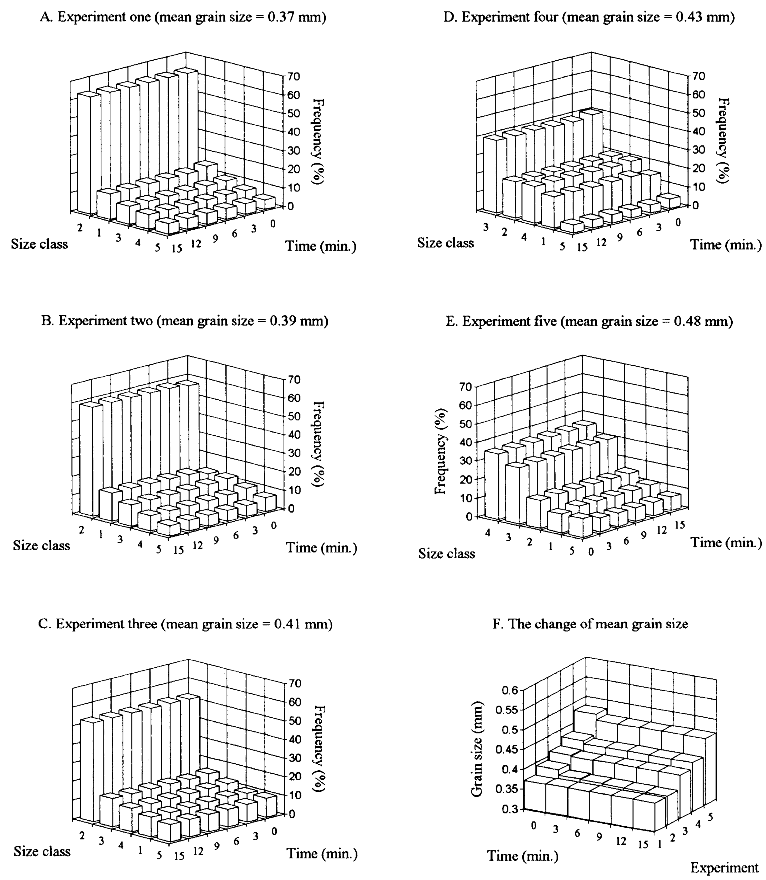

Figure 3. The grain-size characteristics of effective surface particles. The friction velocity $u^* = 0{\cdot}29\,\mathrm{m\,s^{-1}}$. (A–E) The change of grain-size distribution over time (grain size classes: 1, 0·15–0·25 mm; 2, 0·25–0·42 mm; 3, 0·42–0·50 mm; 4, 0·50–0·59 mm; 5, 0·59–1·00 mm in diameter). (F) The change of mean grain size over time. The change of grain-size distribution and the mean grain size at time 0 are for parent material, and at other times are for the effective surface particles

Mean grain size of eroded particles

The mean grain size of the eroded particles for each time period of the experiment was calculated using the following equation:

$$D = \frac{\Sigma W_i d_i}{\Sigma W_i} \quad (i = 1, n) \tag{6}$$

where D is the mean grain size, W_i is the weight of eroded particles in class i, d_i is the grain size of class i, and n is the number of classes.

The change in the mean grain size of the eroded sediment is illustrated in Figures 1F and 2F for the first and second series of experiments, respectively. For nine of the ten experiments, the mean grain size for the first time period was larger than that of the parent material and larger than that for any other time period. In other words, the eroded particles for the first time period had the highest proportion of coarse particles, implying that the coarser particles were more mobile than the finer particles during the initial time period.

Under the lower wind friction velocity ($0{\cdot}29\,\mathrm{m\,s^{-1}}$), the mean grain size of the eroded sediment fluctuated around the mean grain size of the parent material during the subsequent time periods (Figure 1F). With the more mobile coarser particles removed during the first time period and a sufficient supply of particles of different sizes, the mean grain size of the eroded sediment remained about the same over the rest of the experiment.

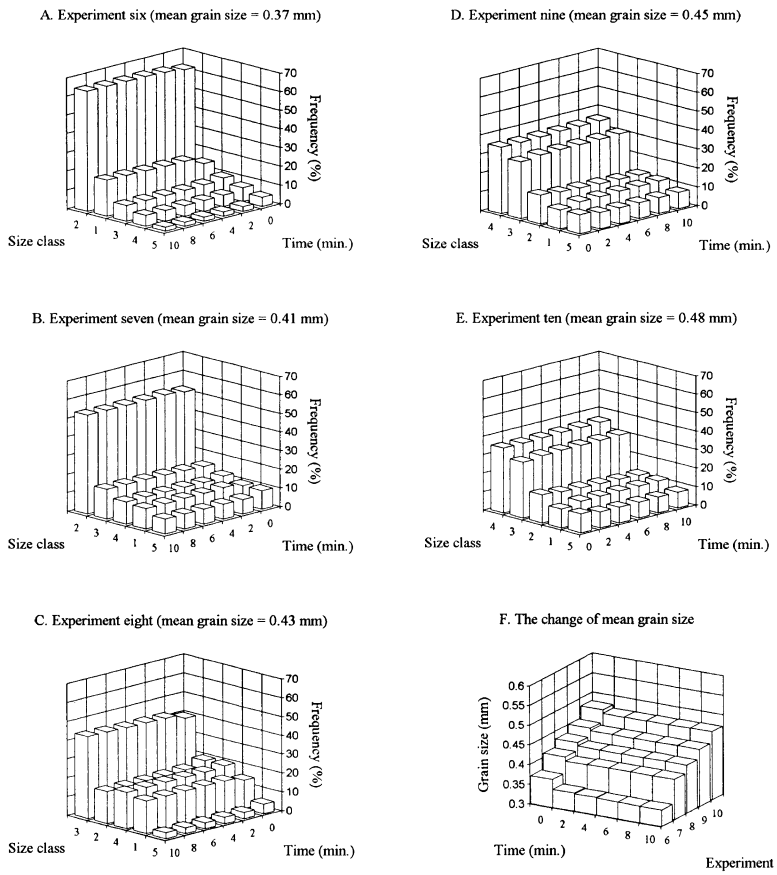

Figure 4. The grain-size characteristics of effective surface particles. The friction velocity $u^* = 0{\cdot}34\,\mathrm{m\,s^{-1}}$. (A–E) The change of grain-size distribution over time (grain size classes: 1, 0·15–0·25 mm; 2, 0·25–0·42 mm; 3, 0·42–0·50 mm; 4, 0·50–0·59 mm; 5, 0·59–1·00 mm in diameter). (F) The change of mean grain size over time. The change of grain-size distribution and the mean grain size at time 0 are for parent material, and at other times are for the effective surface particles

Under the higher wind friction velocity ($0{\cdot}34\,\mathrm{m\,s^{-1}}$), the mean grain size of the eroded sediment decreased slightly during the subsequent time periods (Figure 2F). Compared to the first series of experiments, the second series of experiments had much higher rates of sediment erosion. This could reduce the erodible particle supply from the parent material, particularly for the erodible coarser particles. The decrease in the mean grain size of sediment eroded during the subsequent time periods was probably caused by a decreasing supply of mobile, coarser particles.

Grain-size distribution of the effective surface particles

The grain-size distribution of the effective surface particles is determined by that of the eroded or deposited particles and the parent material particles, and by the surface thickness dimension. For this study, the thickness of the effective surface was established as 1 mm – the largest diameter of the parent material. Using Equations 1, 2 and 4, the grain-size distribution of the effective surface particles was calculated for each time period of each experiment. The results show that the temporal variation in the grain-size distribution of the effective surface particles for all the experiments was minimal over time (Figures 3A–E and 4A–E). This is thought to reflect the fact that all the particles were erodible and selective wind dislodgement was limited.

Mean grain size of the effective surface particles

The mean diameter of the effective surface particles over time was calculated for each experiment using Equation 5. The results are shown in Figures 3F and 4F. They clearly demonstrate that there was a sharp decline in the mean grain size in the first time period, and afterwards the change was minimal. This is because both the

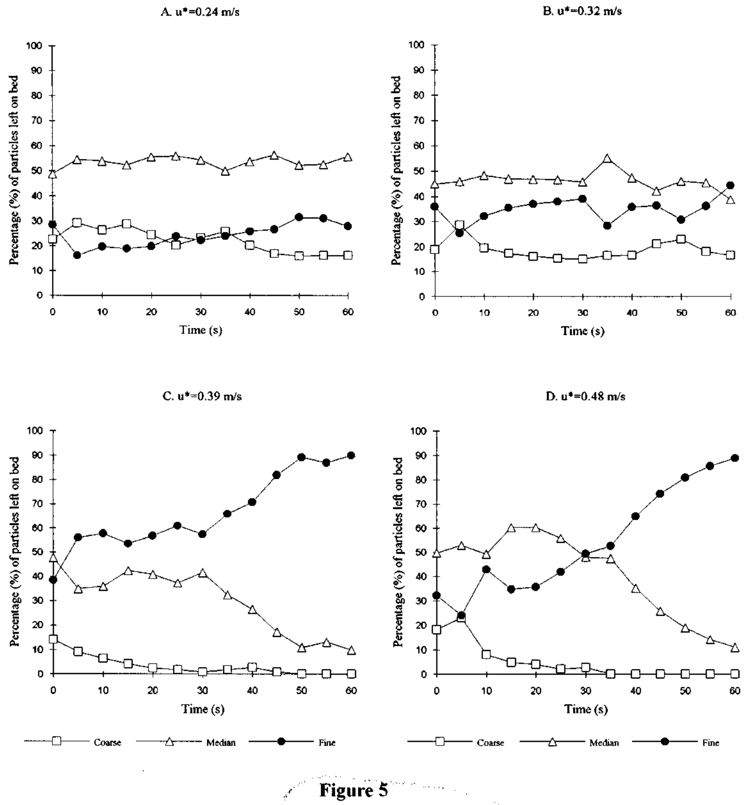

Figure 5. Percentage (%) of coarse, median and fine grains left by wind on the bed (data from Willetts and Rice, 1988)

relative and absolute volumes of large particles eroded during the first time period were higher than during the remaining time periods (Figures 1 and 2).

As expected, the grain-size distribution and the mean grain size of the effective surface particles were inversely related to those of the eroded particles and varied much less over time than those of the eroded particles (Figures 1, 2, 3 and 4). The temporal variation of the grain-size characteristics of the effective surface particles was related to the parent material particles and the eroded particles. The grain-size characteristics of the parent material particles added to the effective surface counteracted the influence of the eroded particles on the effective surface particles, and are responsible for the smaller temporal variation of the grain-size characteristics of the effective surface particles. We recognized that for better examination of the temporal variation in the grain-size distribution of the effective surface particles and interaction between particles of different sizes, experiments should be designed to maximize the sorting process. Sorting is determined by particle size and wind friction velocity, and is a gradual process. It would be preferable to choose a wide size range of particles, wind friction velocity lower than threshold for the coarsest particle, and a long time period.

RELATION BETWEEN PARTICLE TRANSPORT RATE AND PARTICLE SIZE

It is known that for a uniform grain surface the aeolian sediment transport rate is inversely related to particle size. However, the relationship between sediment transport rate and the grain-size characteristics of a non-uniform grain surface is complicated by interaction between the larger and the smaller particles. The transport rate is influenced not only by the particle size but also by the grain-size distribution of particles on the surface. The former determines the particle mobility, while the latter determines the availability of particles at the surface. Gillette and Walker's (1977) observations in the field suggest that the proportion of the eroded particles in individual size classes is very similar to that of the surface particles.

Table I. Counts of coarse (0·355–0·600 mm), median (0·250–0·355 mm) and fine (0·150–0·250 mm) grains left by wind on the bed, from Willetts and Rice (1988)

Time	$u^* = 0{\cdot}24\,m\,s^{-1}$			$u^* = 0{\cdot}32\,m\,s^{-1}$			$u^* = 0{\cdot}39\,m\,s^{-1}$			$u^* = 0{\cdot}48\,m\,s^{-1}$		
(s)	Coarse	Median	Fine	Coarse	Median	Fine	Coarse	Median	Fine	Coarse	Median	Fine
0	539	1161	679	486	1153	923	292	991	799	444	1212	787
5	557	1039	308	445	713	396	110	420	673	187	427	195
10	460	941	342	239	590	392	43	239	385	31	192	167
15	340	619	223	112	302	228	19	191	241	14	172	99
20	264	598	214	69	201	159	9	145	202	6	88	52
25	166	458	195	44	134	109	5	105	172	2	52	39
30	146	342	140	29	88	75	2	87	120	2	34	35
35	133	258	124	22	74	38	3	51	104	0	19	21
40	84	222	107	13	37	28	3	28	75	0	13	24
45	63	209	99	11	22	19	1	19	90	0	8	23
50	55	181	109	9	18	12	0	13	107	0	4	17
55	49	159	94	6	15	12	0	12	80	0	2	12
60	41	141	71	6	14	16	0	8	72	0	1	8

Gillette and Stockton (1989) indicate that the diameter of particles determines not only their threshold friction velocity but also whether the particles are sheltered by other coarser classes or shelter other finer classes. They propose that the effect of non-erodible, coarser particles is to increase the threshold friction velocity for wind erosion of erodible, finer surface particles by sheltering the finer particles. However, they have no data to test whether the larger particles are more mobile than the smaller particles if the wind friction velocity is raised above the threshold for the larger (non-erodible) particles.

Willetts and Rice (1988) investigated particle dislodgement by wind from a flat sand bed in wind tunnel experiments. They measured the variation in particle concentration for coarse, median and fine sand on a single-grain-thick bed over time (Table I). Since their emphasis was on the time decay of concentration of all size sands, the concentration of each individual class was not examined. However, their data clearly demonstrate the mobility difference between coarse particles and fine particles on a non-uniform grain bed. As shown by Table I and Figure 5, both the absolute and the relative number of coarse particles left on the bed by wind decreased more than those of the fine particles in all the four cases. This difference is most pronounced at high wind friction velocities (Figure 5C and D). This supports the earlier conclusion that coarser particles could be more mobile than finer particles provided the wind friction velocity is higher than the threshold for the coarser particles.

CONCLUSIONS

The grain-size characteristics of sediment transported by wind have been studied extensively. While most research has focused on the variation of grain size over space (e.g. Bagnold, 1941; Folk and Word, 1957; Williams, 1964; Chepil and Woodruff, 1957; Gillette, 1974; Gillette and Walker, 1977), this study focused on the variation of grain size over time. We first introduced a method based on the effective surface concept. This is a simple, accurate method for the calculation of the grain-size distribution and the mean grain size of surface particles. We then applied this method to examine the temporal variation of grain-size characteristics under erosion. We found that at wind friction velocities above the threshold velocity for all surface particles, the grain-size distribution of surface particles was very similar to that of the parent material over a short time period of 10 to 15 minutes. We consider this to be a result of the sorting process limited by the high wind friction velocity, the narrow size range of the test sand particles, and the short duration of the experiments. However, the mean grain size of surface particles apparently decreased over the initial time period of 2 to 3 minutes, confirming that a larger particle could be more mobile than a smaller particle when the wind friction velocity is higher than the threshold for the larger particle.

McEwan and Willetts (1993), in a review of the current conceptual model for sand transport by wind, conclude that the lack of data about the size distribution of the grains dislodged from the bed is the main obstacle

to the development of multiple grain-size models. The present data on the grain-size distribution of the eroded particles and the inferred data of the effective surface particles provide insight into the interaction of several grain sizes in aeolian sediment transport processes, and can be used for the development of multiple grain-size models.

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